

Overview of Nondestructive Evaluation Capabilities at NASA MSFC

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Southern Illinois University -
Carbondale

MARSHALL
SPACE FLIGHT CENTER



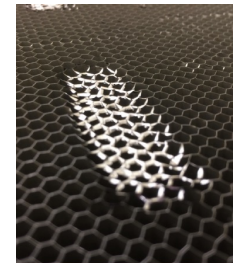
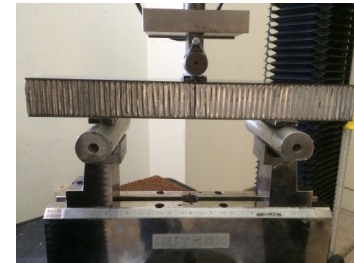
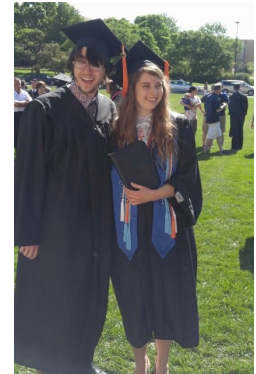
Background

Education:

- University of Kansas
- B.S. Mechanical Engineering May 2017
- Focus areas:
 - Biomedical product development
 - Lithium ion battery life cycle monitoring
 - Mechanical system design, programming

Internship:

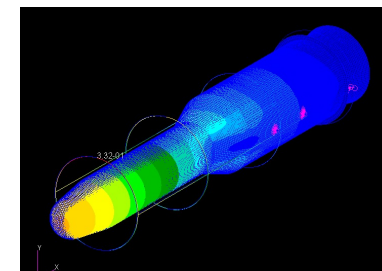
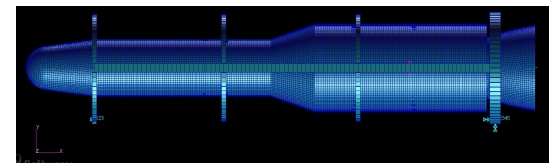
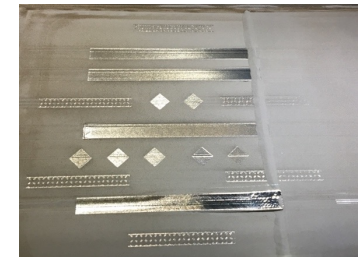
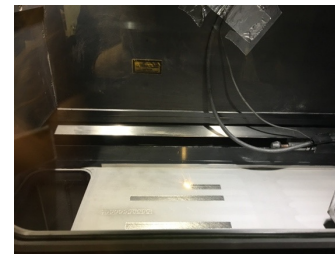
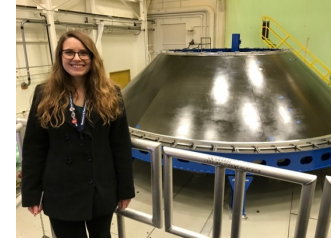
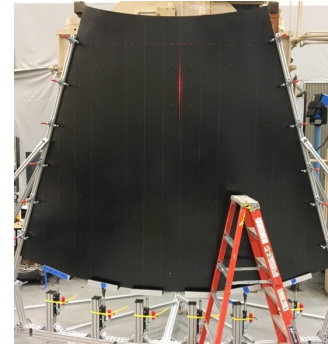
- NASA MSFC, Summer 2016
- Advanced Composites Manufacturing Team (EM42)
- SLS Block 1B Payload Adapter manufacturing
- Composite damage tolerance
 - Intentional core damage, lay-up panels
 - Mechanical testing
 - Determine effect of damage on properties
 - Some exposure to NDE techniques



MSFC Experience

Nondestructive Evaluation Team:

- October 2017 – present
- Composites infrared flash thermography
 - Payload Adapter (PLA)
 - Orion Stage Adapter (OSA)
 - Composites Technology for Exploration (CTE)
 - Shell Buckling Knockdown Factor
- Friction stir weld inspection
 - Ultrasonic testing (UT)
- OSMA NDE Studies:
 - Effectiveness of Penetrameters
 - In-Situ Monitoring for AM Certification
 - Crack/Notch NDE Correlation
- NDE of AM



PIP Rotations:

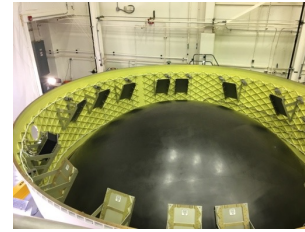
- Additive Manufacturing Team
- Advanced Concepts Office



MSFC Experience

Cool things at MSFC:

- Orion Stage Adapter send-off
- LVSA spray-on foam insulation application
- Pegasus Barge
- Intertank Test Article
- LH2 Tank Structural Test Stand
- LH2 Tank Structural Test Article
- Vehicle Static Test Stand
- Saturn V/BE-4 Engine Test Stand
- Michoud Assembly Facility tour
- Stennis Space Center
 - RS-68 engine test fire



MSFC Experience

US Space & Rocket Center Pathfinder Shuttle Inspection:

- Assisting repair plans – move or repair-in-place
- Eddy current inspection on lifting lug welds



REACTION		NEWTON' S 3 RD		ACTION	
RESPONSE/OUTPUT		NDE METHOD		INPUT	
VISIBLE BLEEDOUT		Penetrant (PT)			
RESONANCE		Mechanical Impedance Analysis (MIA)			
MEASURED ULTRASOUND		Acoustic Emission			
SURFACE DISPLACEMENT		Shearography (SH)			
TEMPERATURE		Thermography (RT)			
MEASURED ULTRASOUND		Laser Ultrasonics (Laser UT)			
		Ultrasonics (UT) / Phased Array UT			
LEAKAGE FIELD		Magnetic Particle (MT)			
		Eddy Current (ET)			
FIELD IMPEDANCE CHANGE		Electromagnetic Acoustical Transducer			
VOLTAGE CHANGE		Electrical Potential Drop (da dN)			
DIELECTRIC DIFFERENCES		Microwave/Millimeter Wave (MMW)			
DIELECTRIC DIFFERENCES		Terahertz (THz)			
		Visible			
IMAGE					
DENSITY PHOTON COUNT		Computed Tomography (CT)			
DENSITY PHOTON COUNT		Backscatter X-Ray			
LATENT FILM DENSITY		Radiographic (RT)			



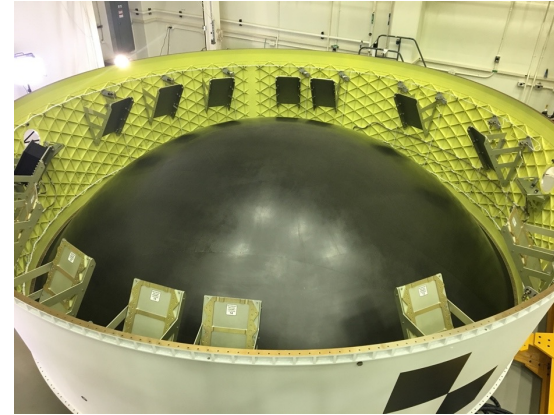
MSFC NDE Capabilities

- Full service NDE lab
 - Facilities, equipment, and expertise for all listed techniques
- What do we inspect?
 - Everything from research test specimens to flight hardware
 - Can deploy most methods across the country when needed
- Technique Development
 - Apply existing methods to specific parts and new challenges
 - Probability of detection studies to understand capabilities & limitations
 - Trade studies between techniques
- Oversight
 - Ensure proper application of NDE principles by and for commercial partners
- Flight Hardware Inspections
 - Perform inspections on welds and composite articles manufactured by or for NASA
- Engineering Support
 - Often called upon to provide critical supporting data in failure investigations
- Emerging Methods
 - Stay current with advances in the field and investigate potential applications
 - Small Business Innovation Research (SBIR) grants help develop new methods



MSFC NDE Focus Areas

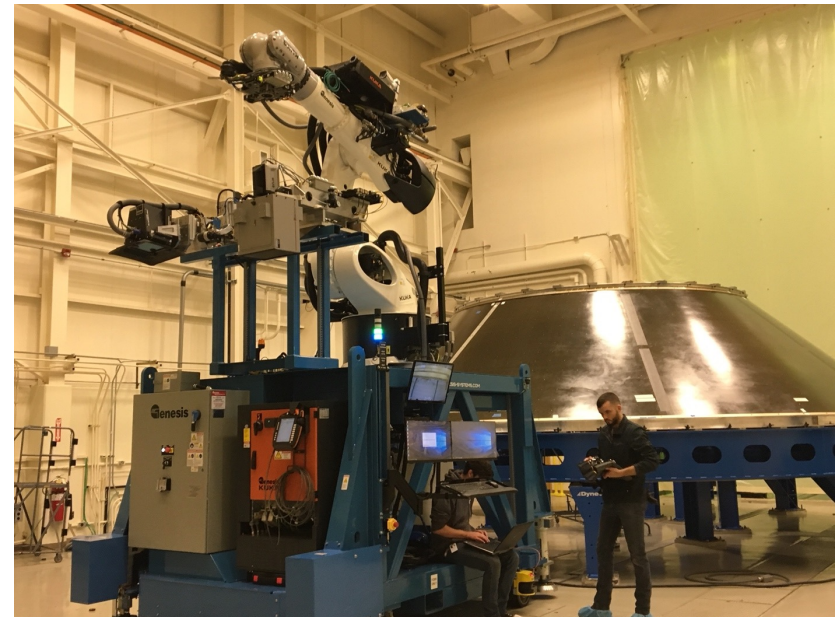
- Friction Stir Welding
 - Radiography, ultrasonics, penetrant
- Composites
 - Thermography, shearography, ultrasonics
- Additive Manufacturing
 - Mostly computed tomography (CT)
 - Defects inherent to AM
 - Defects in complex internal features
 - In-situ NDE
- NDE in Space
 - In-situ NDE for Multi-Material FabLab
 - Volumetric (CT) capability



Recent flight hardware: Orion Stage Adapter (OSA)



Recent flight hardware: Launch Vehicle Stage Adapter (LVSA)



Payload Adapter NDE System (PANS) Demonstration Article

NDE Methods – Surface / Near Surface

EDDY CURRENT

*Various Probe Designs:
Surface, Bolt Hole, Weld*

- Weld panels
- Bolt holes, fasteners
- Some AM
- Special applications

MAGNETIC PARTICLE

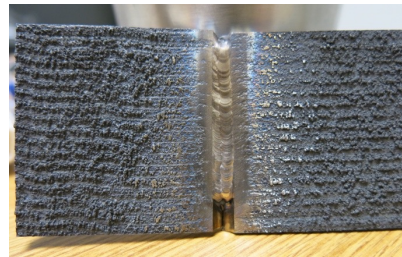
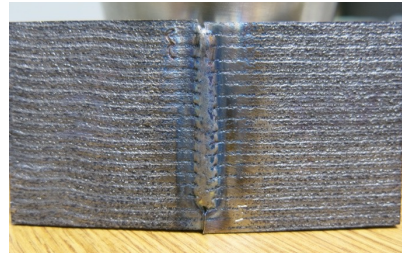
Applicable only to ferromagnetic material (e.g. steel)

- Used infrequently for weld inspection
- Pressure vessels, lifting equipment

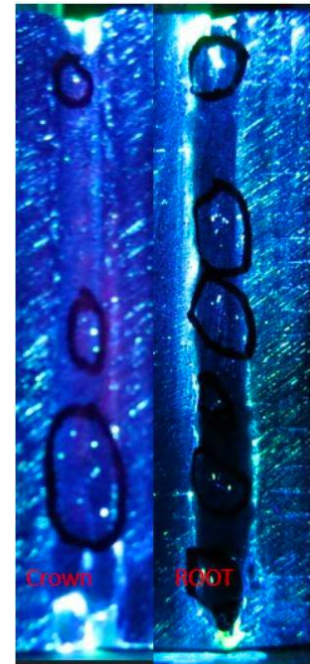
LIQUID PENETRANT

*Fluorescent / Visible,
Water-Washable, Post-Emulsifiable*

- Friction Stir Weld
- SLM
- Welded DED Panels



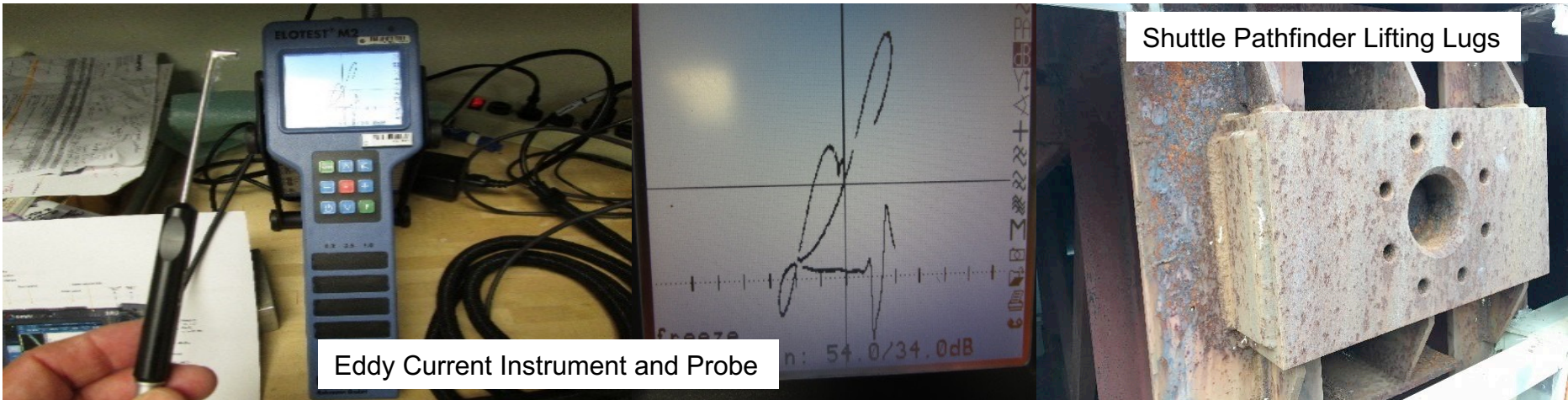
Blown powder JBK-75
Welded



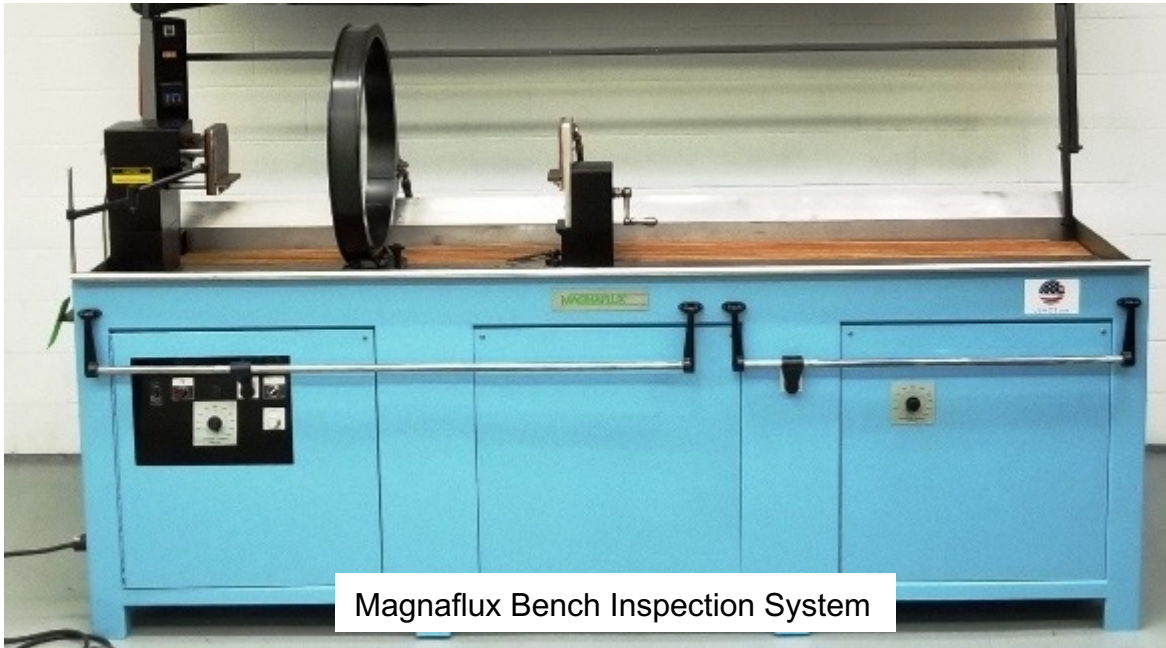
Porosity throughout weld



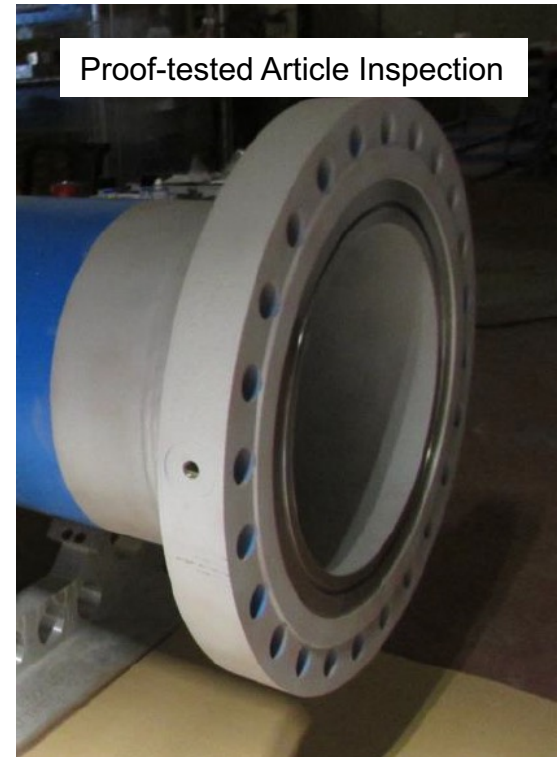
Eddy Current



Magnetic Particle



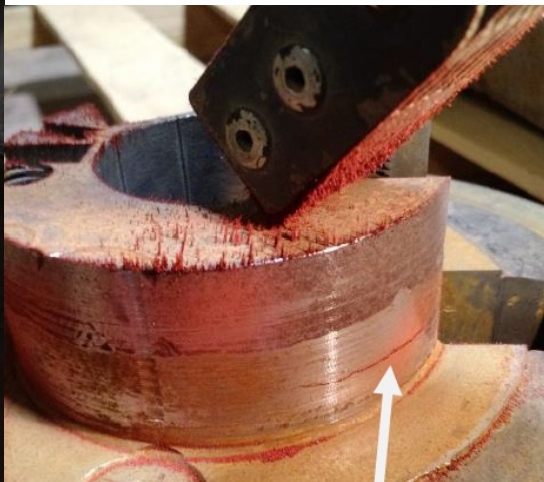
Magnaflux Bench Inspection System



Proof-tested Article Inspection



Handheld Yoke Instrument



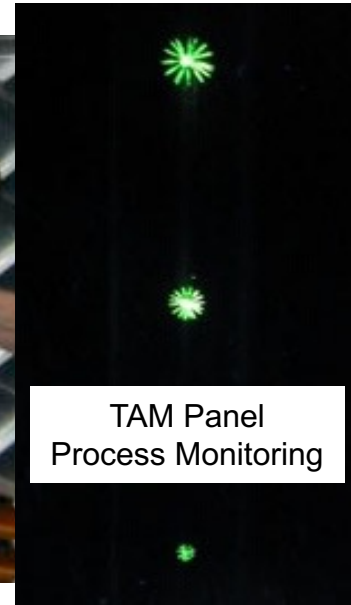
Dye Penetrant



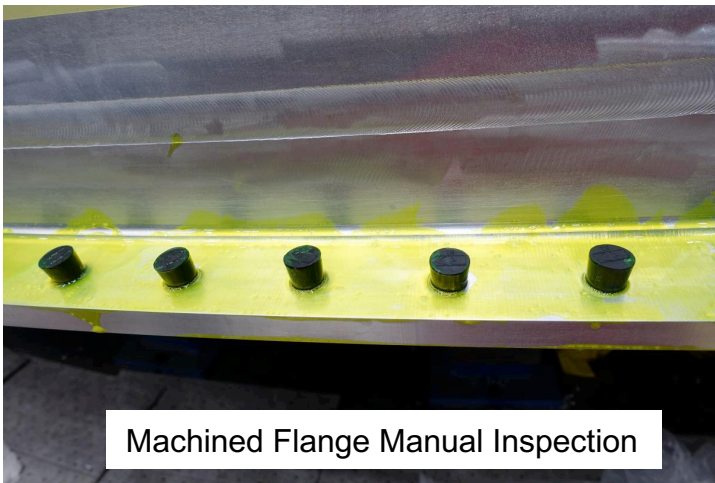
Penetrant Line with spray/wash, dryer, developer, and inspection stations



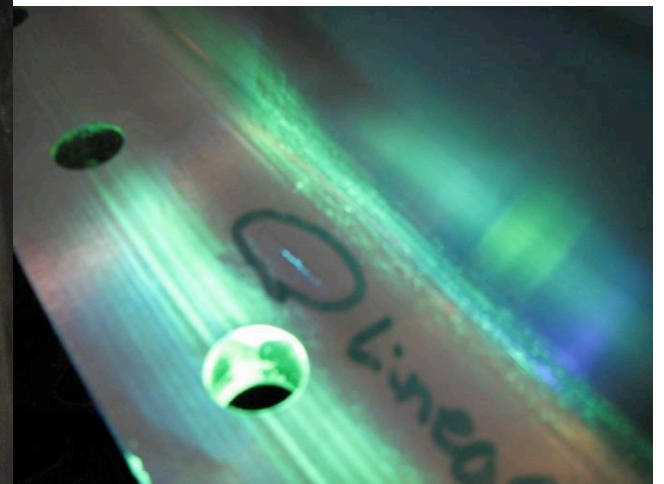
Manual Weld Inspection



TAM Panel
Process Monitoring



Machined Flange Manual Inspection



NDE Methods - Volumetric

ULTRASONICS

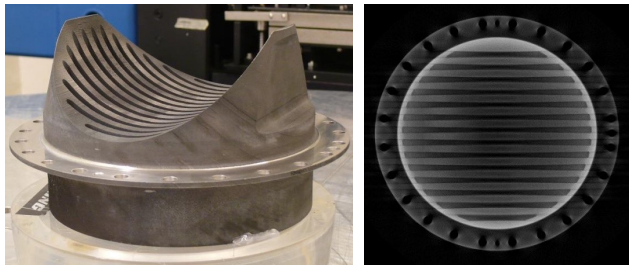
Immersion / Contact, Phased Array, Pulse-Echo / Through-Transmission

- Friction Stir Weld
- Composites
- Some AM

RADIOGRAPHY

Film, Computed Radiography, Digital

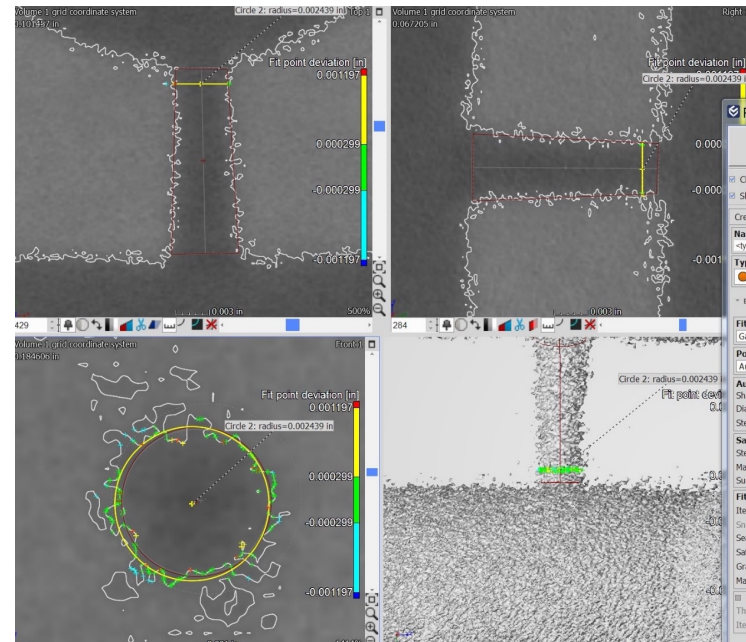
- Friction Stir Weld
- AM



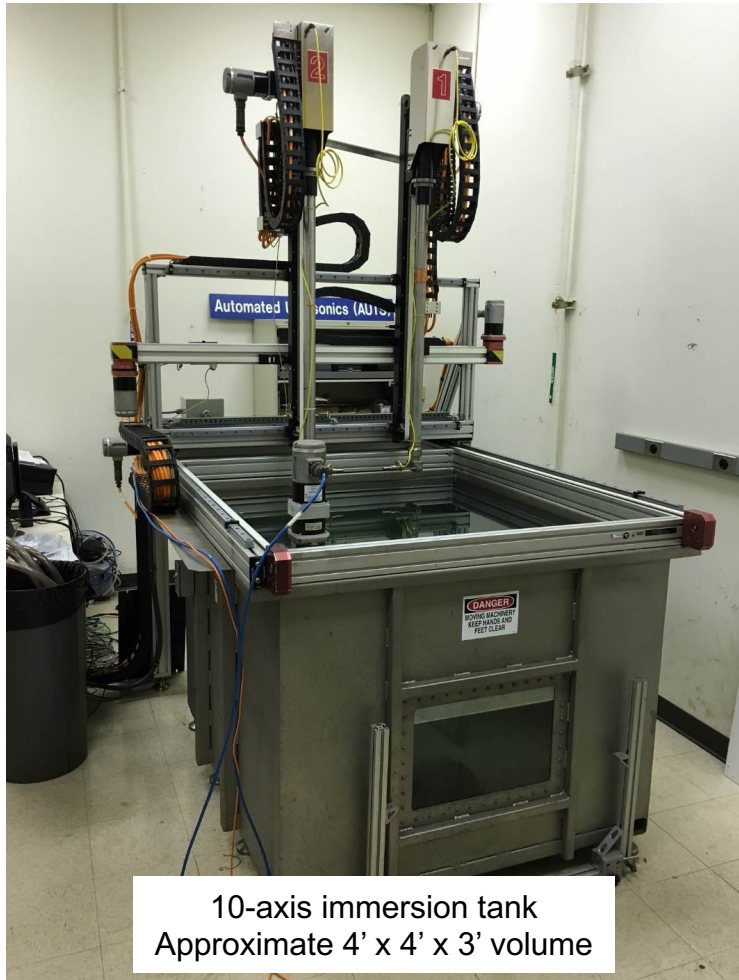
COMPUTED TOMOGRAPHY

2 MeV High Energy Micro-/Mini-focus

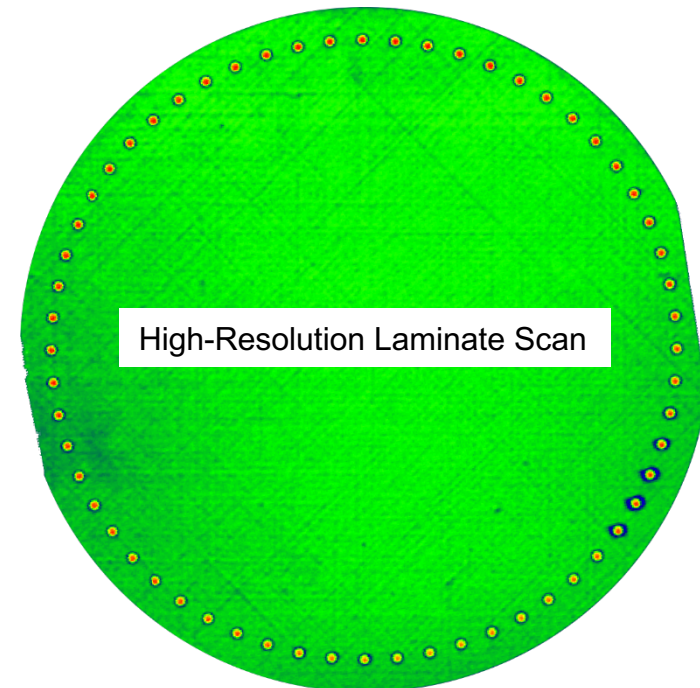
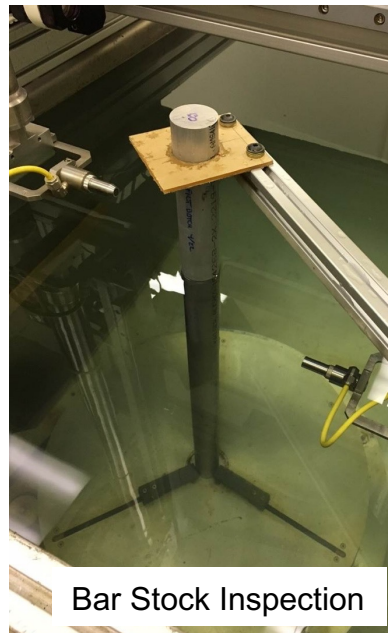
- Most AM
- Composites
- Dimensional Metrology



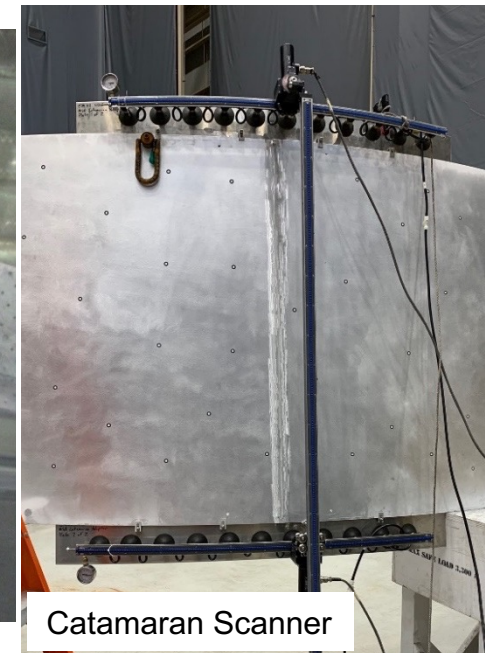
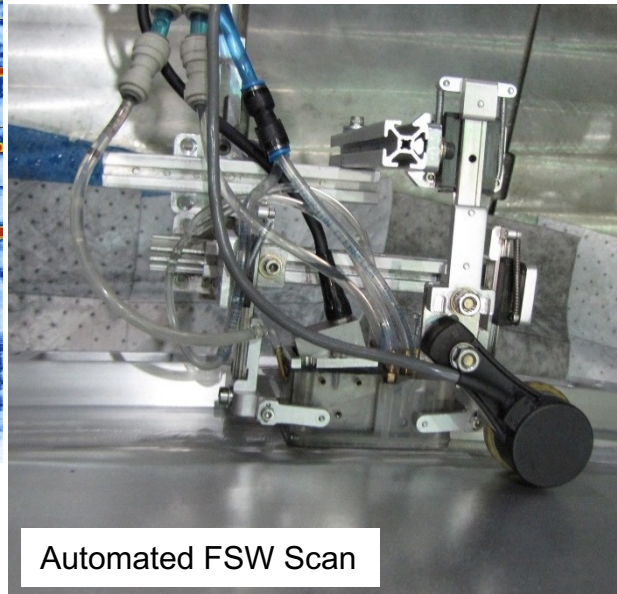
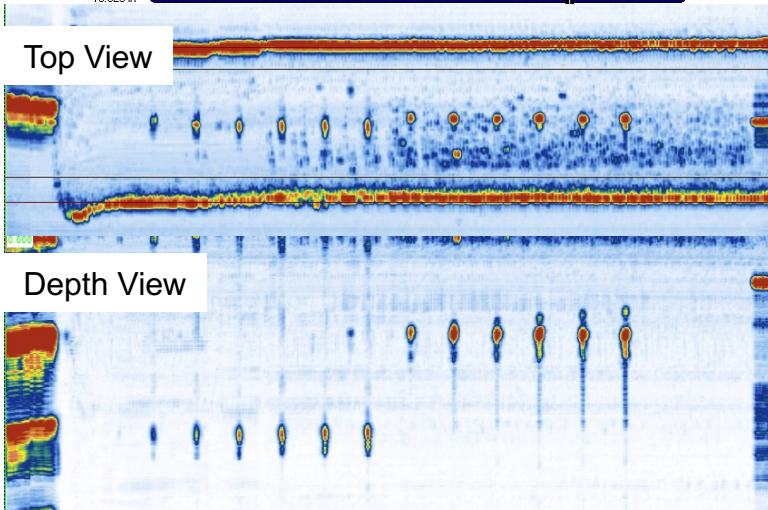
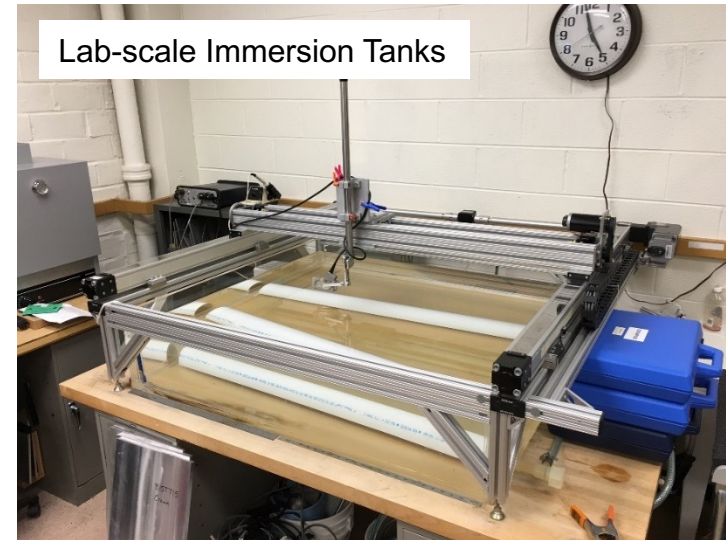
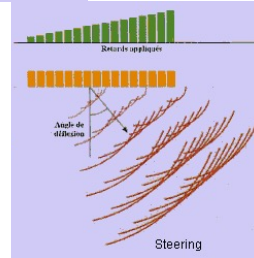
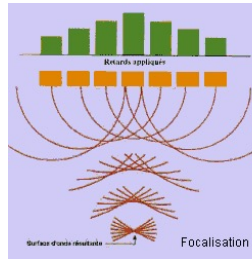
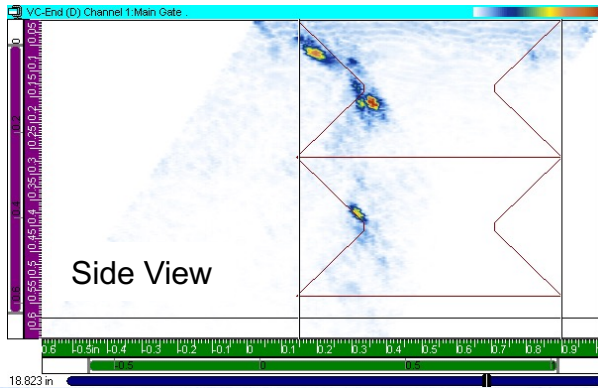
Conventional Ultrasonics



Basic Instrument and 0-degree Probe



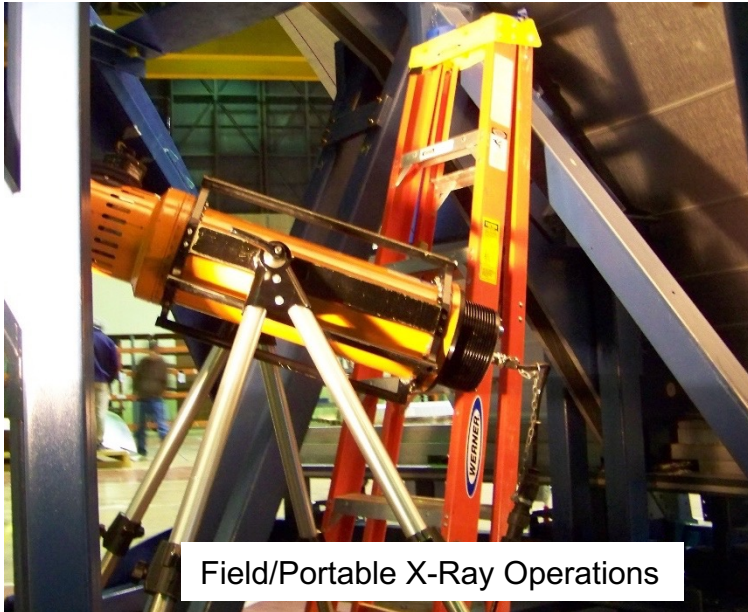
Phased Array Ultrasonics



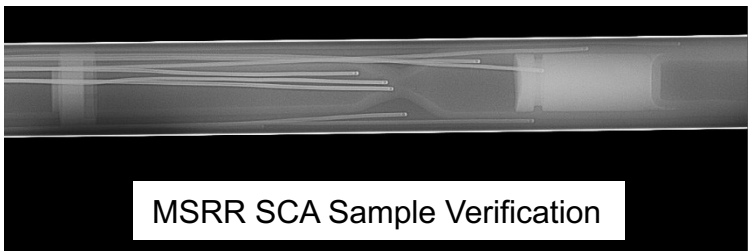
Radiography



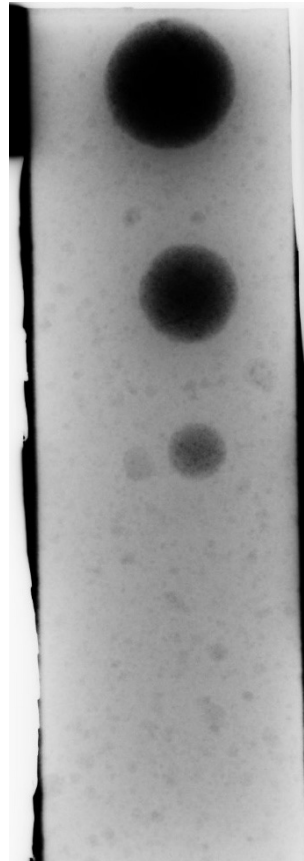
Weld Defect Generation Panel



Field/Portable X-Ray Operations



MSRR SCA Sample Verification

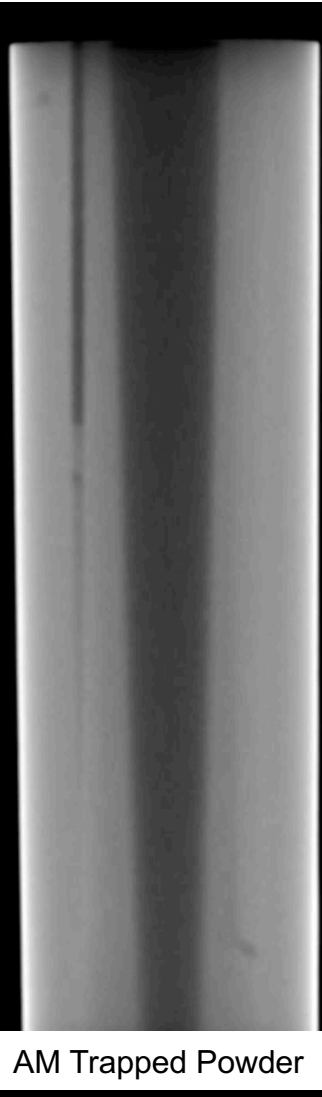
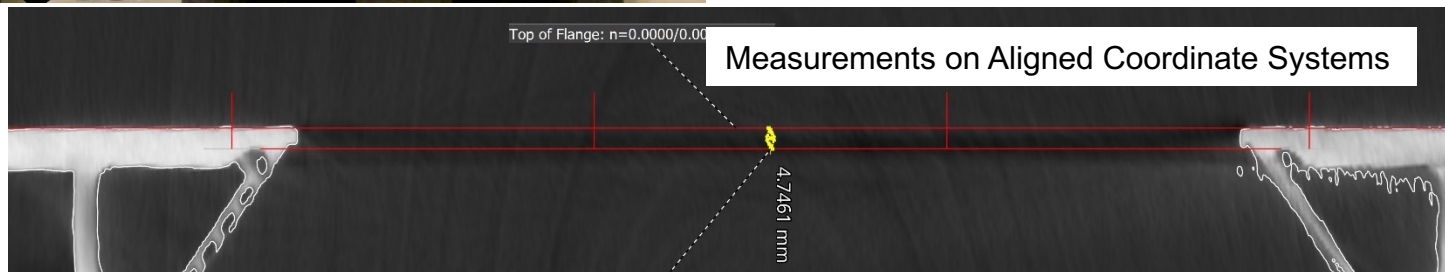
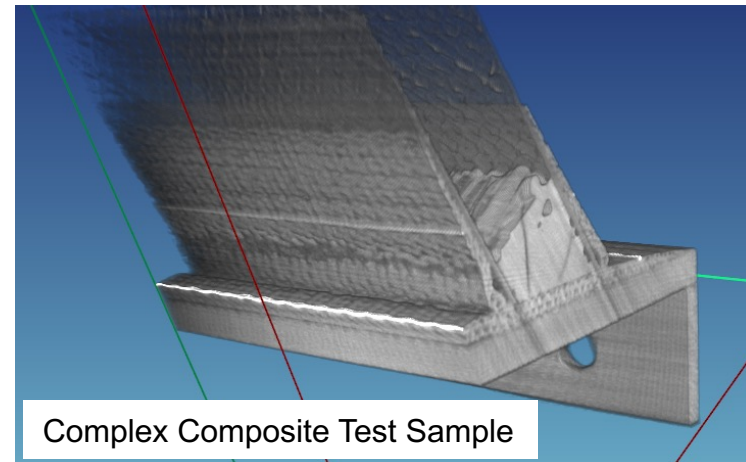
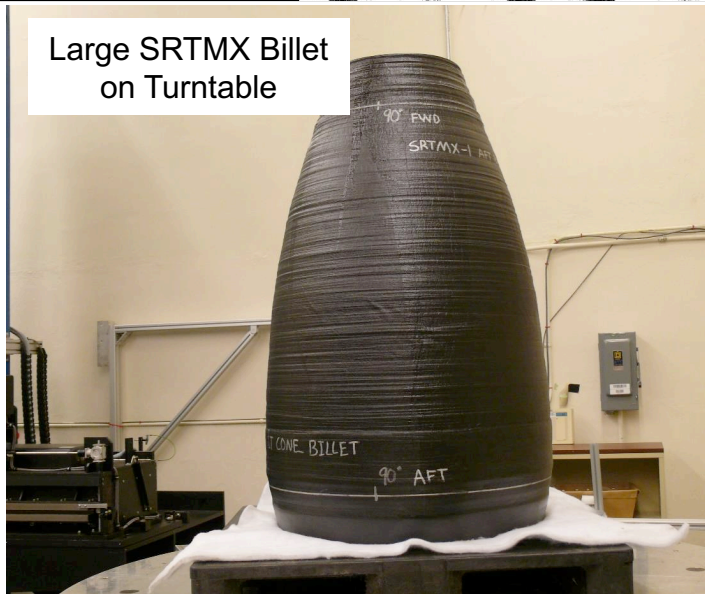
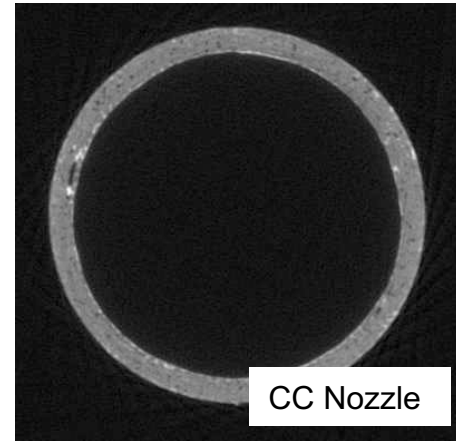
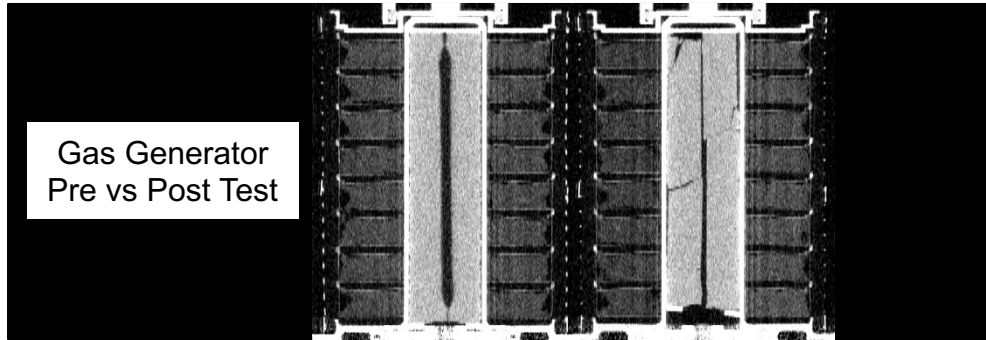


MMPACT Concrete



Valve Inspection In X-Ray Cell

Computed Tomography



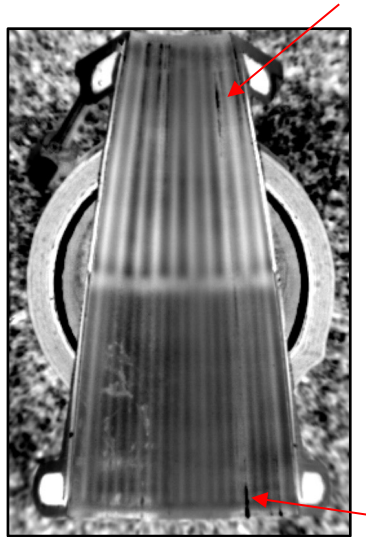
NDE Methods – Special Applications

INFRARED FLASH THERMOGRAPHY

- Composites
- Developmental metal applications
 - AM trapped powder
 - Friction stir weld



Formalloy DED
HR-1 Nozzle



Thermographic
Image

can see flow channels,
potential oxidation

SHEAROGRAPHY

Vacuum OR Heat Laser Shearography

- Composites
- Spray-on Foam Insulation

ACOUSTIC EMISSION

- Layered Pressure Vessels
- Special Applications

MICROWAVE/MILLIMETER WAVE

- Spray-On Foam Insulation

PROCESS-COMPENSATED RESONANCE TESTING

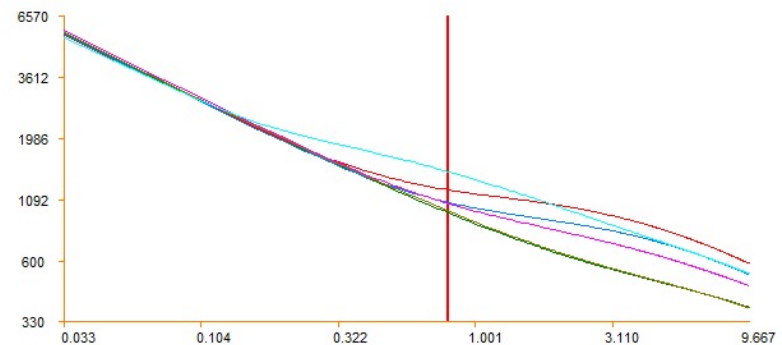
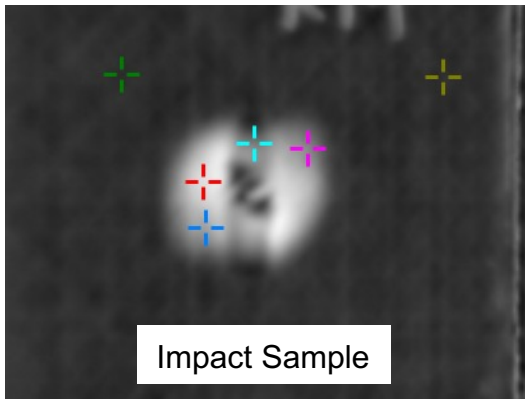
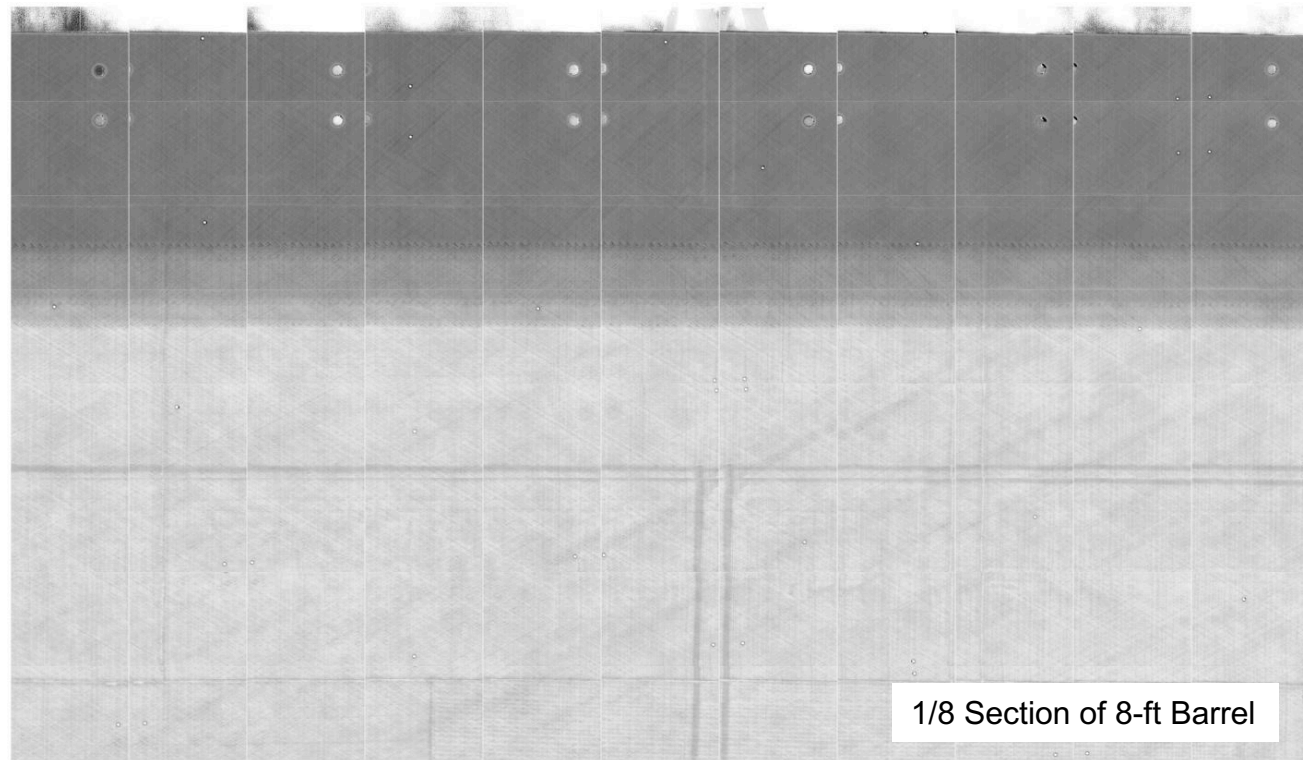
- Part-to-itself comparisons
- Additive manufacturing
witness test coupons



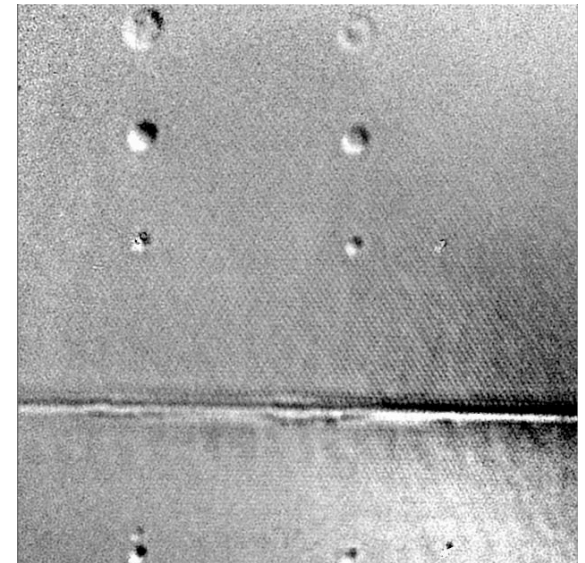
Flash Thermography



Inspection System



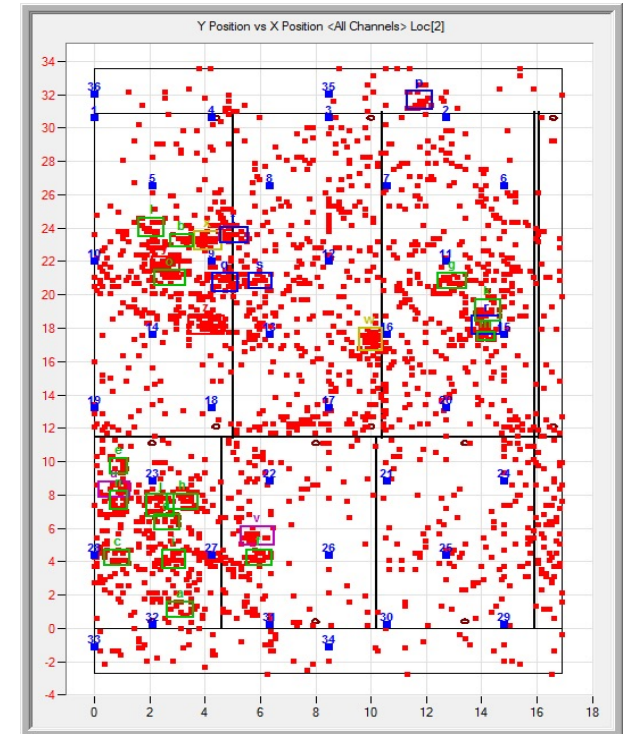
Shearography



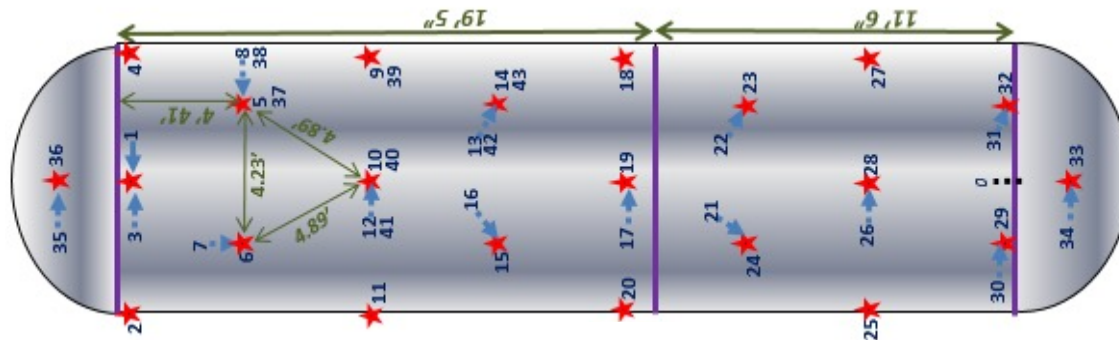
Acoustic Emission



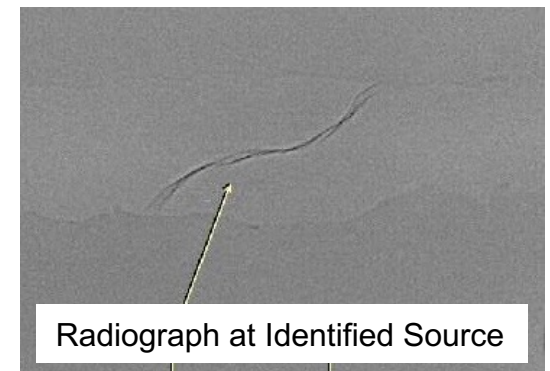
Layered Pressure Vessel



Location Plot After Test



Sensor Locations



Radiograph at Identified Source

Process Compensated Resonance Testing

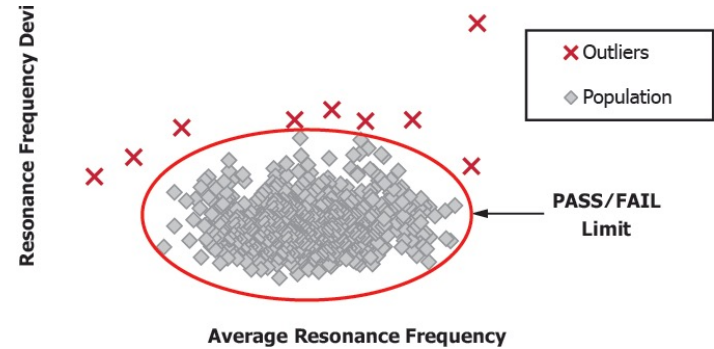
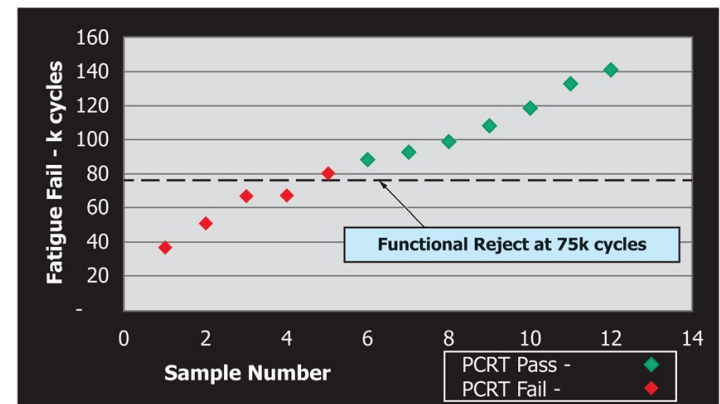
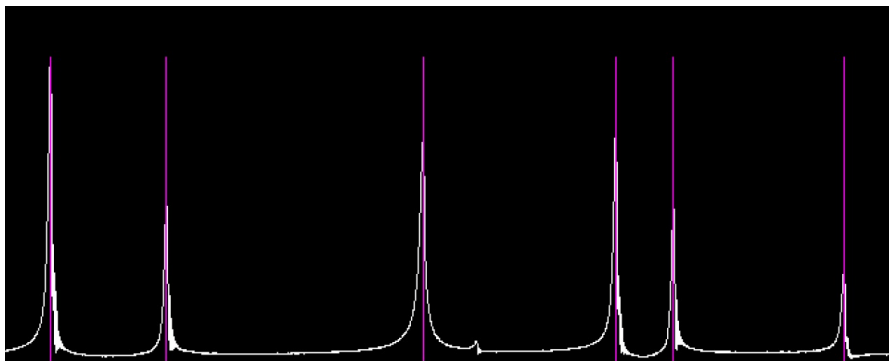


Illustration of Outlier Screening



PCRT Pass/Fail Prediction of Fatigue Failure

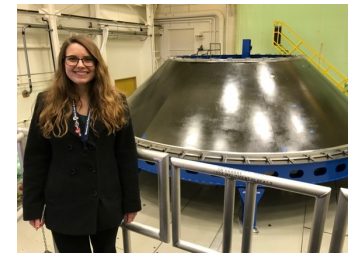
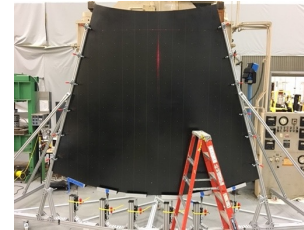


Resonance Peak Detection

NDE Projects

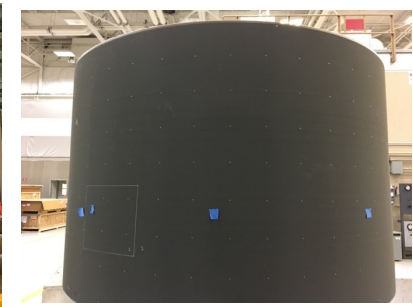
Payload Adapter:

- Inspect test panels and demonstration articles
 - Use primarily infrared flash thermography (IRFT)
- Advise on and mitigate inspectability concerns
 - Change from aluminum honeycomb to foam core
- Payload Adapter Automated NDE System (PANS)
 - Robotic inspection system
 - Capability for IRFT, shearography, and ultrasonics



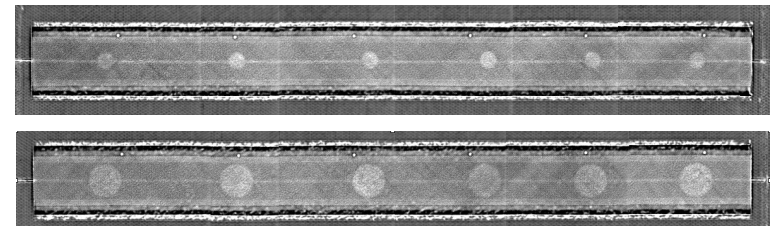
Shell Buckling Knockdown Factor:

- Informed knockdown factors for buckling critical structures
- Manufacture reduced-mass composite barrels
- Inspect test barrels before and after mechanical testing
 - Use IRFT, shearography, ultrasonic testing (UT)



Composites Technology for Exploration:

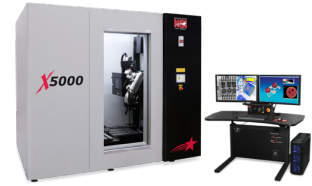
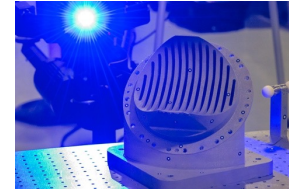
- Inspect composite panels with various layups
 - Includes bonded joints
 - Use IRFT, UT
- Inspect panels before and after mechanical testing



NDE Projects

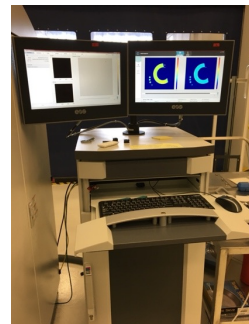
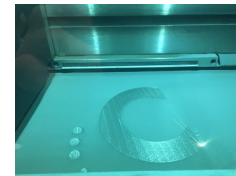
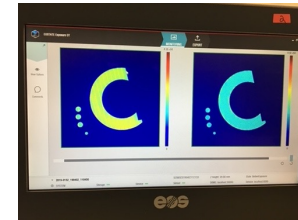
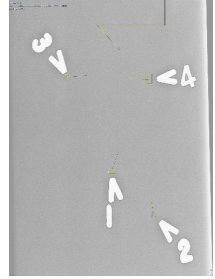
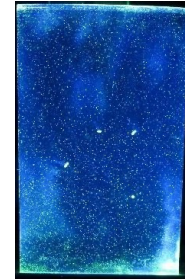
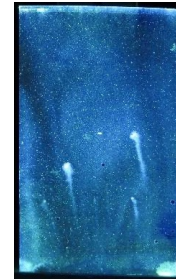
Additive Manufacturing:

- Typically inspect with computed tomography (CT)
 - New micro-/mini-focus system
- OSMA study for use of traditional NDE techniques
 - Laser crack panels from UTC Dayton
 - Inspect with penetrant, radiography, UT, CT



In-Process Monitoring:

- EOState Monitoring Suite on EOS M290
- AMSENSE Monitoring on Concept Laser M1
- How does monitoring data correlate to defect state?
 - Working various studies, certification approach
- SBIR and CAN collaborations



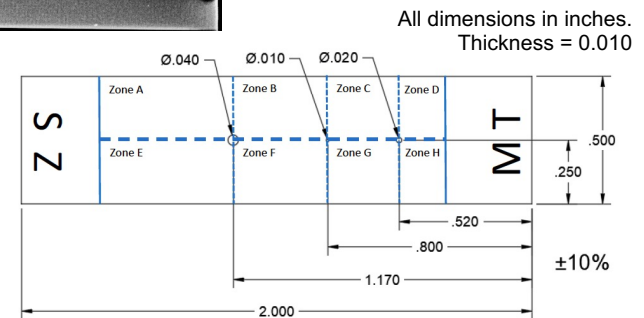
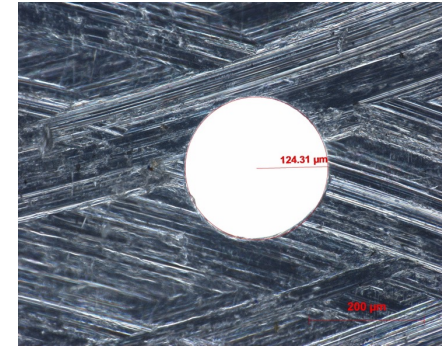
ASTM Involvement:

- Transfer of authority from NASA White Sands Test Facility
- Committee E07 (NDE) and F42 (AM)
- International Conference on Additive Manufacturing (ICAM)
- AM Center of Excellence projects and workshop
- Standard Guide for In-Situ Monitoring of Metal Additively Manufactured Aerospace Parts

NDE Projects

Penetrator Effectiveness Study:

- OSMA NDE Program Funded Study
 - PI: Erin Lanigan, Dr. Sam Russell
- Image quality indicator for radiography
 - 2% of the thickness of the part
 - Smallest hole is 1T (1 x thickness)
- NASA-STD-5009 requires 1T-sized hole
 - Subjective visual evaluation
 - Knowing hole location can bias detection
 - Size of grains in computed radiography imaging plates is similar to that of the 1T hole



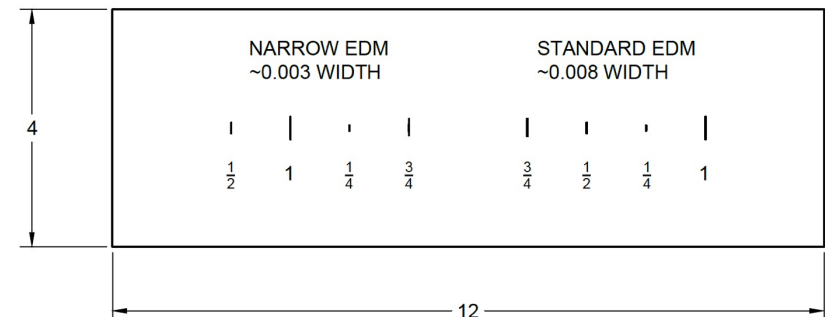
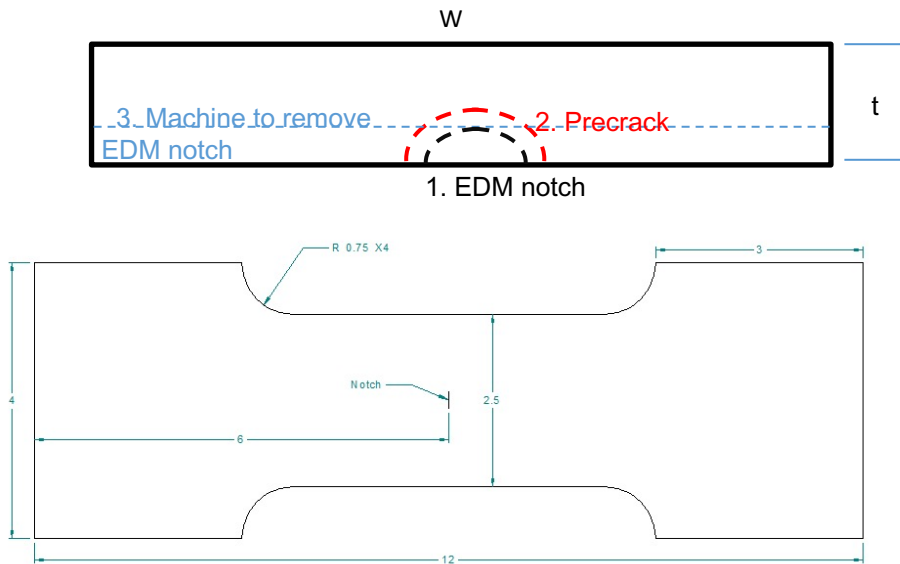
Objective:

- Randomize the placement of the 1T hole
- Perform a probability of detection study for 1T-sized holes in random locations
- Quantify the reliability of 1T hole detection as a measure of image quality
- Measure the contrast-to-noise ratio (CNR) in each hole that the operator can visibly detect.
 - Compare to the new 2.5 CNR requirement in revised NASA-STD-5009a
- Develop best practices approach for use of hole penetrameters as image quality indicators

NDE Projects

Crack Correlation Study:

- OSMA NDE Program Funded Study
- Need to quantify detection capability in real part geometries
 - Difficult to add a crack to a part, so notches are used
 - Investigating the use of ½ size EDM
- Develop a quantitative transfer function of NDE response:
 - Notch in a panel vs. crack in a panel
 - Notch in a panel vs. notch in a part
- Relating NDE signal measurements with visual detection
- Also investigating effect of etching on RT signal



NASA-STD-5009

“Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components”

- Basic NDE requirements for NASA systems with fracture control
- Requirements for personnel & process control, documentation, and capability
- Leading agency-wide team preparing Rev C

Two classes of technique:

- **Standard NDE**
 - Accepted methods and associated flaw sizes considered generally detectable when performed with due care and based on historical datasets
 - Instrument calibration against a properly-sized defect considered acceptable demonstration
- **Special NDE**
 - Methods not otherwise listed
 - Procedures to detect flaws below the Standard size range or outside requirements
 - Requires demonstration of a 90/95 detection capability with a statistically-based study (size of flaw with 90% probability of detection at 95% confidence)





Questions?

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marshall